

# Multiple Characteristics of Ionospheric Variability Patterns

Michael Mendillo  
Boston University  
Center for Space Physics  
phone: (617) 353-2629 fax: (617) 353-6463 email: [mendillo@bu.edu](mailto:mendillo@bu.edu)

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## LONG-TERM GOALS

Various observational tools are available for the study of F-layer irregularities in the equatorial region. These include optical observations of the depletion of electron density (groundbased and spacebased), GPS phase fluctuations, DMSP and ROCSAT *in situ* observations of ion density depletions, radar observations of coherent backscatter from equatorial irregularities, and ionospheric soundings. Each makes contributions to observational studies and each has its limitations. Our long term goal, using a full set of these measurements, is to study the physics of the equatorial regions, particularly during periods of irregularity development. Subsequent coupling of high latitude observations and equatorial observations will lead to forecasting where and when intense irregularities occur in various world areas and how they affect transmissions from satellites.

## OBJECTIVES

Equatorial ionospheric irregularities, particularly in the region 10° to 20° north and south of the magnetic equator, are the cause of radio communications fades of up to 20 dB in episodic occurrence patterns. This latitude region includes cities such as Santiago, Bogotá, Cairo and Singapore. Some receivers can deal with fades of this type while others cannot. Field program users of satellite-to-ground or to ocean-based reception links need to know that problems are of natural causation rather than equipment malfunctions. Methods of dealing with the fading can only be designed using knowledge of the geophysical and environmental characteristics of these irregularities (size, velocity etc.)

## APPROACH

Our approach to studying geophysical disturbances as the cause of communications disruptions involves the use of unique (in house) regional data sets funded by ONR, and state-of-the-art models (both empirical and computer simulation codes), in conjunction with global satellite observations available via the internet. Our own optical measurements involve all-sky camera observations of ionospheric structures taken at a site near the Equatorial Ionization Anomaly (EIA) region in the southern hemisphere, i.e., from our ONR-sponsored observing system at the El Leoncito Observatory in Argentina. To assess communications links, we study GPS signal phase fluctuations using an online network of over 60 ground stations throughout the EIA latitude band in both hemispheres. To understand the types of ionospheric structure disturbance responsible for the GPS effects, we use the sensors onboard the DMSP and ROCSAT satellites that give direct ionospheric ion density measurements along each orbit.

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The optical all sky measurements also allow us to identify unusual patterns of drift that occur during large-scale, solar-terrestrial disturbances known as geomagnetic storms. Our approach has been to study a number of individual storms and to search for characteristics that are common to all and thus capable of being forecast. Results obtained in the South American region are then tested at other longitudes (where we do not have optical data) using the GPS and DMSP satellites. In this way we are able to examine the longitude consistency and robustness of the forecasting techniques.

Key individuals participating in this work are:

- (a) Michael Mendillo, Professor of Astronomy, serves as PI and directs the overall analysis consistent with current-day theory in space physics.
- (b) Jeffrey Baumgardner, Senior Research Associate in the Center for Space Physics, designs, constructs and repairs all instrumentation; he participates in data analysis and interpretation.
- (c) Joei Wroten, Senior Staff Researcher, is in charge of data analysis and archiving; she maintains our website, conducts image processing, and works with the PI on ionospheric storm studies.
- (d) Carlos Martinis (Ph.D. candidate, now post-doctoral Research Associate) conducts the analysis and interpretation of the imaging data from El Leoncito, Argentina.
- (e) Megan King (undergraduate research assistant) works with Dr. Martinis on analysis and portrayal of GPS ionospheric data for case study and overall morphology studies.

## **WORK COMPLETED**

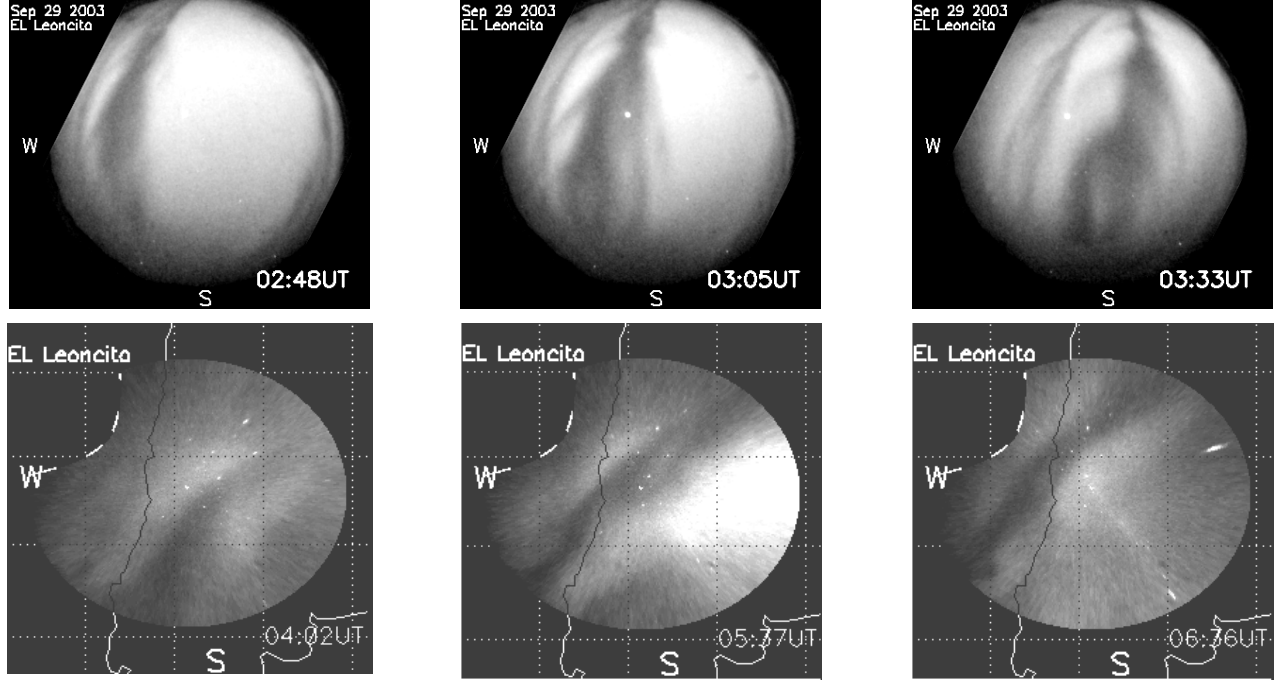
The major accomplishment during the second year of this grant was the first bi-hemispheric study of how ionospheric irregularities map along geomagnetic field lines in the American longitude sector. This established how optical imaging systems in one hemisphere can be used to specify where ionospheric disturbances occur in the other hemisphere. In addition, such results address the core physics involved in irregularity generation.

## **RESULTS**

### *Background*

Boston University's ONR-sponsored imager is at the El Leoncito Observatory in the western Andes of Argentina (31.8 S, 69.3 W). This site has relatively high geographic latitude for its location under the southern crest of the equatorial EIA region (18 S magnetic latitude). Thus, this location fosters the study of how physical processes originating at the magnetic equator propagate into lower mid-latitudes. This low-to-high latitude coupling is a frontier area of research in the ionospheric physics community, and our efforts offer leadership science in that area (Martinis et al., 2006). This imager has identified four types of strongly variable phenomena: (1) highly-structured airglow depletions associated with the Rayleigh-Taylor instability [responsible for equatorial spread-F (ESF)]; (2) brightness waves (BW) associated with the midnight temperature maximum (MTM) reported on under previous ONR grants; (3) strong airglow enhancements associated with the positive phase/SED aspects of TEC during geomagnetic storms, and (4) simple (non-structured) bands of alternating dark and bright airglow emission with characteristics matching a Perkins-like instability. Disturbance types (1)

and (4) are the ones most able to cause radiowave scintillations and GPS disruptions, and thus we concentrate on those effects under this grant. Examples of each type are given in Figure 1. In the top panel, dramatic ESF plumes can be tracked in their eastward motion caused by thermospheric winds via dynamo action with the geomagnetic field. In the bottom panel, the relatively simple bands of dark and bright airglow have ionospheric irregularities that move in the opposite direction, showing it to be a disturbance pattern quite distinct from the ESF effects noted above.

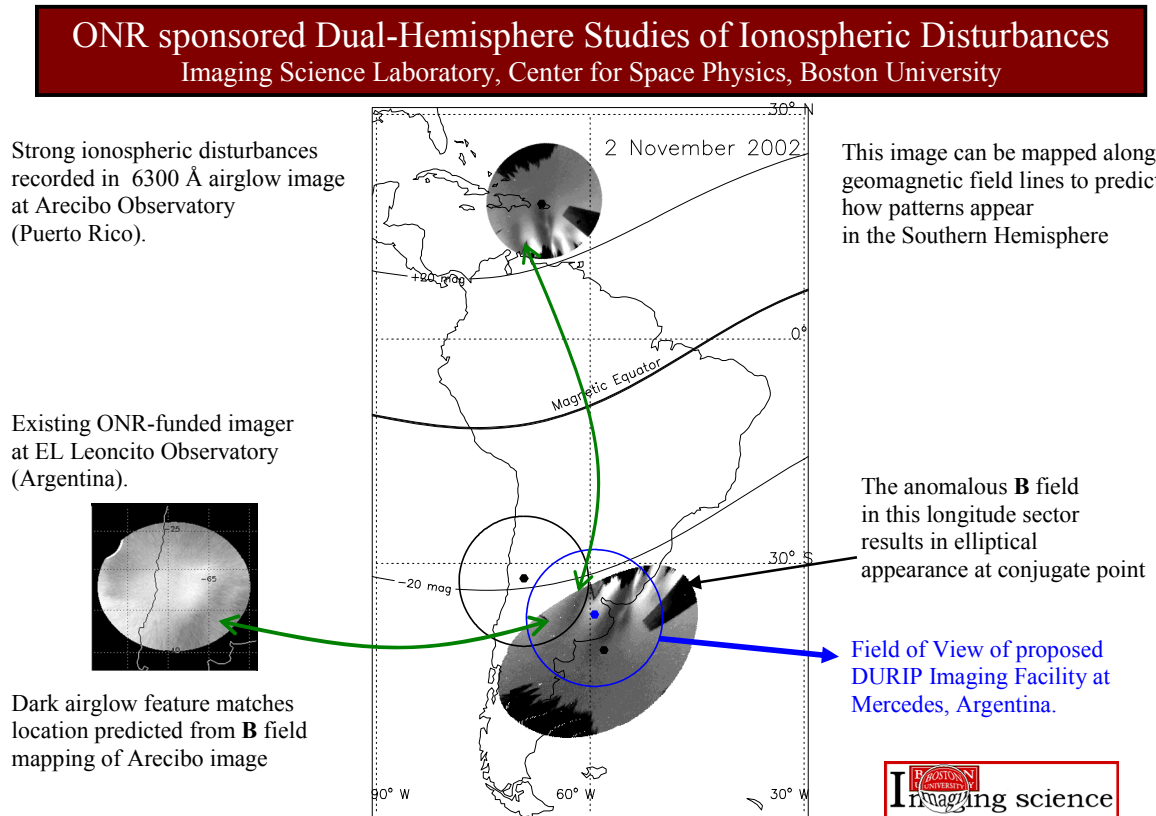


**Figure 1: Top panel: raw images showing the eastward motion of very structured airglow depletions. Bottom panel: geographically unwarped images at 300 km showing an airglow band moving towards the north-west. Notice the different orientation and structuring of these two features (taken from Martinis et al., 2006) that both cause radiowave scintillation effects upon GPS signals.**

### New Results

The question posed was “Do such optical signatures of a structured ionosphere map consistently from one hemisphere to the other?” To explore this concept in detail, we used a similar set of images taken at the Arecibo Observatory in the northern hemisphere (in Puerto Rico) and mapped each pixel of an image along the Earth’s geomagnetic field lines to their corresponding locations in the ionosphere of the southern hemisphere. This “conjugate point” mapping is a complex process in this particular region of the globe because the Earth’s magnetic field is highly distorted near South America (the so-called South Atlantic Anomaly (SAA) in the terrestrial magnetic field). Arecibo’s conjugate point is near, but not coincident with, our optical field-of-view (FOV) from El Leoncito, and that introduces some uncertainties when relating specific spatial-temporal signatures. Nevertheless, some very significant and exciting effects were obtained. For example, in Figure 2 we show an example of the overall relationship, together with its implications for follow-up investigations. There are several items to notice in this figure: (1) the circular FOV from Arecibo maps to a distinctly oval-shaped FOV

in the southern hemisphere due to the SAA geometry, (2) this southern FOV includes a small portion of that from our imager at El Leoncito, so partial validation of effects can be obtained from the overlapping area, and (3) a vastly improved set of conjugate point studies can be achieved by installing a second imager at a location in Argentina much closer to Arecibo's set of conjugate magnetic field lines. A site survey was conducted and a location in Mercedes was found to house such an instrument. Thus, a proposal was submitted to the ONR DURIP competition for 2007 to make such coordinated experiments possible. The additional benefit of an all-sky imager at Mercedes is that longitude patterns can be mapped over the full region covered by the joint Mercedes-El Leoncito, a two-FOV system that can test temporal prediction methods for these longitudinally-moving structures.



**Figure 2.** A summary of how airglow images can be mapped along geomagnetic field lines from one hemisphere to another. In this particular example, the validation comes from the ONR sponsored imager at El Leoncito that covers only a small portion of the image mapped from Arecibo. The new instrument location proposed to DURIP is shown with the blue field-of-view, one that covers a far more complete portion of the mapped Arecibo image, thereby allowing for more successful tests of portraying and predicting inter-hemispheric ionospheric disturbances.

## IMPACT/APPLICATIONS

Much of current understanding of the morphology patterns of communications-disruptive ionospheric irregularities comes from data taken at sites at or near the magnetic equator, such as Huancayo and Jicamarca (Peru) and Manila (Philippines). However, the very strongest amplitude and phase

fluctuations of GPS and FLEETSATCOM signals come from stations in the Equatorial Ionization Anomaly (EIA) region, a latitude band in each hemisphere located between about 10° to 20° from the geomagnetic equator. In these regions, amplitude fluctuations to 20 dB have been noted, even at the high frequencies of GPS. Forecasting the timing and extent of communications dropouts due to ionospheric disturbances are the central applications products of the studies we are conducting.

## TRANSITIONS

In order to move towards the goal of forecasting the effects of ionospheric irregularities on communication system, we must understand the patterns of occurrence during both quiet and disturbed periods. The former is well in hand for ESF-related effects (“airglow depletions”) in that the seasonal-longitude patterns already determined are essentially regional forecasts of *ionospheric disruptive climate*. The day-to-day variability during those seasons remains the elusive topic. This type of *ionospheric weather* is under active study, and forecast techniques are within reach. Progress has been made on the major challenge of understanding *the regional role* of geomagnetic storms in enhancing or inhibiting the occurrence of equatorial and low-latitude irregularities (Martinis et al., J. Geophys. Res., 2005). That aspect of our study dealt with the determination of effects caused by *severe ionospheric weather*, and at a much localized level within several world regions. The analogy to tropospheric disturbances would be to tornadoes, i.e., very severe and highly localized micro-climate. The more demanding problem is day-to-day disturbances, and their consistency in both hemispheres within specific longitude sectors. While we have taken a major first step in understanding this topic the past year, it is not ready for a transition to operational use. Our ongoing studies aim to do that, but many more case studies are needed to establish confidence in proposing realistic, operational forecasting scenarios. Similarly, the separate type of “airglow bands” and the irregularities associated with them have not been studied sufficiently (during both quiet and storm conditions) to warrant realistic transitions to operational use. Our prior studies of the ionosphere’s total electron content (TEC) storm effects, on the other hand, have achieved a level of closure between observations, theory and modeling and forecasting methods are within operational reach (Mendillo et al., 2006).

## RELATED PROJECTS

None

## PUBLICATIONS

Martinis, C., and M. Mendillo, Equatorial spread F-related airglow depletions at Arecibo And conjugate observations, J. Geophys. Res., 112, doi:10.1029/2007JA012403, 2007 [published, refereed].

Mendillo, Michael, Storms in the ionosphere: Patterns and processes for total electron content, Rev. Geophys., 47, RG4001 doi:10.1029/2005RG000193, 2006 [published, refereed].

Martinis, C., M. Mendillo, and M. King, GPS phase fluctuations at equatorial and low latitude stations during extreme solar activity conditions, Proc. International Beacon Satellite Symposium, 11-15 June, 2007, Boston College, Chestnut Hill, MA, 2007 [published, un-refereed].

**PATENTS**

None

**HONORS/AWARDS/PRIZES**

None